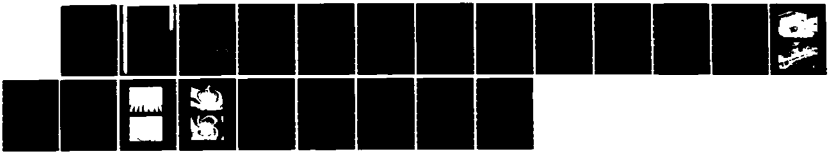
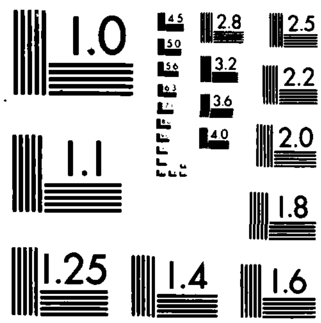
AD-A174 048 EXPERIMENTAL ASPECTS OF IN-PLANE DISPLACEMENT MEASUREMENT USING A MOIRE F..(U) AERONAUTICAL RESEARCH LABS MELBOURNE (AUSTRALIA) J D'CRUZ ET AL. JUN 86 1/1

UNCLASSIFIED ARL/STRUC-TM-440 F/G 14/5 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(12)

ARL-STRUC-TM-440

AR-004-473

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

Structures Technical Memorandum 440

EXPERIMENTAL ASPECTS OF IN-PLANE DISPLACEMENT MEASUREMENT USING A MOIRE FRINGE TECHNIQUE

by

J. D'Cruz, B.L. Lawrie, K.C. Watters and S.J. Rumble

Approved for public release.

JUNE 1986

AR-004-473

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORIES

Structures Technical Memorandum 440

EXPERIMENTAL ASPECTS OF IN-PLANE DISPLACEMENT MEASUREMENT USING A MOIRE FRINGE TECHNIQUE

by

J. D'Cruz, B.L. Lawrie, K.C. Watters and S.J. Rumble

SUMMARY

A description is given of the techniques used to photograph gridded specimens and of the optical processing of the photographs to produce moire fringe images. Details and results of photographing the moire images are presented.

POSTAL ADDRESS: Director, Aeronautical Research Laboratories,
P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

CONTENTS

1. INTRODUCTION

This report describes in detail the experimental procedure used at ARL to implement the moire fringe method for measuring in-plane displacements.

The moire fringe method is a well established full-field procedure for measuring displacements, and a large range of techniques has been developed for its implementation; Reference 1 gives a review of those techniques. The technique developed at ARL was devised to facilitate automatic processing of the fringe patterns by a TV camera linked to a computer. The ARL technique consists of applying a grid to the surface of a specimen, loading the specimen, photographing the deformed specimen grid, and analysing the photograph in an optical processor to produce a moire fringe pattern. A detailed description of these steps follows.

2. THEORY

Moire fringes can be formed when two gratings of nominally the same frequency, or harmonics, are superimposed. The fringes arise from slight distortions of one grating relative to the other. The grating which is undistorted serves as the reference. The other grating is attached to the surface of a specimen, and deforms when the specimen is loaded. The moire fringes are contours of the in-plane displacement component of the specimen surface, in the direction normal to the reference grating rulings.

Two orthogonal in-plane displacement components can be obtained by using a two-dimensional grid on the specimen surface, instead of a one-dimensional grating. The distorted grid is compared to the reference grating separately in the two principal directions. The implementation of this principle at ARL involves superimposing a photograph of the deformed specimen grid on the reference grating in a coherent optical processor. A description of the processor is given in Section 7.

Any magnification error or rotational misalignment between the specimen grid and the reference grating will also generate moire fringes. It is important to eliminate any such false fringes, leaving only a fringe pattern which truly represents the distortion of the specimen. Techniques used to achieve this are described in the report.

For a more complete coverage of the theory of moire fringe formation see References 2, 3 and 4.

3. SPECIMENS

Two specimens were used to demonstrate the performance of the technique: a cold-worked bolt hole specimen and a J-integral specimen. The geometries of these specimens are shown in Figures 1 and 2. The J-integral specimen was made of 7010-T73651 aluminium alloy and was cracked to the length shown in Figure 2 by fatigue loading, prior to the grid being applied to its surface. The cold-worked bolt hole specimen was made of A7-U4SG aluminium alloy and was cold worked after the grid had been applied to its surface.

4. SPECIMEN PREPARATION

The specimen surfaces were polished prior to the application of a thin coating of Hoechst PK-14 Positive Photo Resist (diluted 1:1 with Butyl Acetate). The

specimens were spun at approximately 400 r.p.m. and the resist solution poured rapidly over their central area. However, this technique resulted in streaking of the film coating. This problem was minimized by varying the strength of the Butyl Acetate dilution. The specimens were then baked in an oven for 10 minutes at 70°C.

On cooling to room temperature, the J-integral and cold-worked bolt hole specimens had a 40 lines/mm and a 20 lines/mm ronchi master grid respectively, clamped to their surfaces. The assemblies were then exposed to UV light. The light source was a portable UV lamp placed 2 ft from the specimen and provided a light intensity of 860 $\mu W/cm^2$ at the specimen surface. Exposure time was approximately 10 minutes. It was found that the correct exposure time was dependent upon the thickness of the resist coating, and the temperature and time of the baking. Development of the exposed specimen grid was in a solution of Ozasol positive developer replenisher for 1 minute. Drying was effected with a hot air blower.

5. SPECIMEN LOADING

The Fatigue Technology Incorporated split-sleeve process was used on the cold-worked bolt hole specimen. The cold working process involved a maximum interference level of 4.2% before the mandrel was withdrawn.

The J-integral specimen was loaded in a portable Hounsfield Tensometer. A tension load was applied through the two bolt holes of the specimen. The specimen was loaded to 3.17 kN with photographs taken at 0, 1.06, 2.11, 3.17, 0 kN levels.

6. SPECIMEN PHOTOGRAPHY

Schematic diagrams of the optical arrangements used for photographing the J-integral and cold-worked bolt hole specimens are shown in Figures 3 and 4 respectively. A photograph of the J-integral arrangement is shown in Figure 5. The specimens and the camera were mounted on a large concrete block supported by soft springs. The cold-worked bolt hole specimen was held in a clamp. It was photographed before cold working, then removed, cold worked, and replaced for photography after cold working. The Hounsfield Tensometer, in which the J-integral specimen was loaded, was mounted on the concrete block in front of the camera.

The resolution and chromatic aberration of the Schneider camera lens were of an order sufficient for a 40 lines/mm grid to be sharply defined when flash lighting was employed. The magnification of the image and rotational misalignment of the film mount, were adjusted with the aid of a clear glass focussing screen, on which there was a grid of the same frequency as the reference grating in the optical processor (see Section 7). The errors in magnification and alignment produced a moire fringe pattern and were reduced by minimizing the number of moire fringes observed. A Panasonic 30X light scope was used to assist in focussing the image. The interdependence of the focus and magnification required an iterative adjustment procedure to be used. The flash illumination angles found to produce the best results were 45° and 15° for the J-integral and cold-worked bolt hole specimens respectively. At other angles the J-integral specimen images suffered from pronounced streaking from the photo resist coating, which degraded the quality of the moire fringes. The acute angles of illumination of the cold worked bolt hole specimen led to slightly uneven exposure. This problem could be rectified by the use of an additional flash lamp on the opposite side.

As previously remarked, the J-integral and cold-worked bolt hole specimens had 40 lines/mm and 20 lines/mm grids respectively. Both were photographed at a lens aperture f11 and unit magnification, using Kodak technical pan film 2415 (estar-AM base). The higher spatial frequency of the J-integral specimen necessitated the use of Kodak HC-110 fine grain developer at a dilution of 1 part to 19 parts water. For the cold-worked bolt hole specimen, Kodak D19 developer was adequate.

The development times were 8 minutes for the Kodak MC110 and 4 minutes for the Kodak D19, both at 20°C.

7. OPTICAL PROCESSING

Figure 6 is a photograph of the optical processor used to generate the moire fringe images, while Figure 7 is the corresponding schematic representation. The light source is a 100 watt mercury arc lamp developed at ARL. Its light output is focused by lens L_1 through a Spectro-Film narrow band filter (peak wavelength = 5462 Å, band width = 40 Å) and a pinhole. The pinhole filter increases the spatial coherence of the light beam. The beam is then collimated by a Tropel Model 280 Laser Collimator (L_2).

The collimated beam of partially coherent, monochromatic light then passes through the photograph of the specimen grid. This creates the input space signal for the first Fourier transform lens, L_3 (see Reference 5 for a full specification of the Fourier transform lenses). The image in the transform plane of lens L_3 is a two dimensional array of bright spots on a dark background (see Figure 8). The spatial filter F_1 is located in the transform plane and consists of two suitably sized and spaced holes in an opaque sheet. It transmits the spots corresponding to the plus and minus first order beams from the specimen grid. The expanding beams from these transmitted spots pass through the second Fourier transform lens L_4, which creates the inverse transform in the plane of the reference grating G_2. Thus, the filtered image of the specimen grid is superimposed on the reference grating and moire fringes are generated. Reference gratings of the same frequencies as the specimen grids were used, namely 40 lines/mm and 20 lines/mm for the J-integral and cold-worked bolt hole specimens respectively. The emergent light from the reference grating is again transformed by lens L_5 (Schneider-Kreuznach 9926639 Symmar 1:5.6/240) and filtered by F_2. The filter transmits only the zero order beam to the camera. A high contrast moire fringe image may then be seen through the camera viewfinder and photographed.

The displacement component represented by the moire fringe pattern depends on the orientation of the spatial filter F_1 and the reference grating G_2. Referring to Figure 8, if the horizontal (-1, 0) and (+1, 0) spots are allowed through by F_1 and the rulings of the reference grating are vertical, then the horizontal displacement component will be represented. Conversely, if F_1 and G_1 are rotated 90° so that the vertical (0, -1) and (0, +1) spots are allowed through by F_1 and the rulings of the reference grating are horizontal, then the vertical displacement component will be represented.

Contrast was found to be critically dependent on the longitudinal position of the reference grating G_2. The components of the optical processor were initially set up in positions dictated by the nominal focal lengths of the lenses (see Figure 8). However it was found that contrast could be significantly improved by making a slight longitudinal adjustment to the position of G_2. Such adjustment had no apparent effect on the pattern of the moire fringes.

Rotational misalignment between the specimen grid and the reference grating was eliminated by lateral tilting of the reference grating. This was done by adjusting screws at the base of reference grating holder. Rotational alignment was deemed to have been achieved when the number of fringes in the field was qualitatively assessed as being a minimum. The crude tilt adjustment system was a problem because it tended to induce longitudinal tilt in addition to the lateral tilt. A micrometer adjusted rotation stage would be better.

Finally, it was possible to counteract any magnification errors in the specimen grating photography by altering the positions of elements G_1, G_2, L_3, L_4, F_1 of the processor to make it slightly magnifying or reducing as appropriate. Magnification errors were identified when a photograph of the undeformed specimen grid produced a linear fringe pattern which could not be eliminated by rotational alignment. The procedure followed was to increase the spacing between L_3 and L_4 by a nominal amount (say 100mm), then slightly change the spacing between G_1 and L_3 and make the opposite change to the spacing between G_2 and L_4. The change (either increase or decrease) to the spacing between G_1 and L_3 was performed interactively while viewing the fringe pattern, until all fringes from the undeformed specimen grid photograph were eliminated. This procedure is somewhat complex and disturbs the optical processor from its design condition. Therefore, great care should be taken in the specimen grid photography not to induce any magnification error.

8. PHOTOGRAPHY OF MOIRE FRINGE IMAGES

The moire fringe images were photographed on Ilford FP4 film using an Olympus OM4 with a 65-200 mm f4 zoom lens set at 200 mm and in close focus mode. The lens mount included three extension rings totalling 46 mm. To obtain satisfactory images it was necessary to mount the optical processor on a vibration isolated optical table, and also to reduce air currents in the room.

Examples of moire fringe images for the J-integral and cold-worked bolt hole specimens are shown respectively in Figures 9 and 10. The exposure and development conditions are given in Table 1. The longer exposure and development time required to produce Figure 9(b) compared to 9(a) was a direct consequence of the lighting in specimen photography highlighting the grid in one direction more strongly than the other.

Figure	9(a)	9(b)	10(a) and (b)
Exposure time (mins)	4	12	8
Development time at 20°C (mins)	9	11.5	9

TABLE 1 EXPOSURE AND DEVELOPMENT CONDITIONS FOR MOIRE FRINGE IMAGES. (DEVELOPER ID11 AT 1:1 DILUTION)

9. DISCUSSION

During initial investigations into photographing the specimens, comparisons of Agfa-Gevaert Holotest 10 E75 holographic plates and Kodak technical pan film were made. It was found that, whilst the higher resolution of the 10E75 plates produced better results, they lacked the sensitivity required for flash photography. Flash photography was developed as a vibration elimination measure, to extend the in-plane moire technique to specimens loaded in standard testing machines.

The exposure times needed to photograph the moire fringes were quite long. These times could be significantly reduced with the use of a commercial mercury arc light source or a high powered laser. The exposure times could also be reduced by improving the specimen preparation process to eliminate streaking and to boost the contrast between the grid lines and the background.

References

1. Sciammarella, C.A., The Moire Method - A Review, Experimental Mechanics, Nov. 82, p 418.

2. Guild, J., The Interference Systems of Crossed Diffraction Gratings, London, Clarendon Press, 1956.

3. Durelli, A.J. and Parks, V.J., Moire Analysis of Strain, Englewood Cliffs, New Jersey, Prentice-Hall Inc., 1970.

4. Cloud, G.L. "Simple Optical Processing of Moire-grating Photographs", Experimental Mechanics, August 1980, pp. 265-72.

5. Steel, W.H., "A Simple Lens for Optical Fourier Transforms", Journal of Optics, Vol. 2 No. 2, July - Sept. 1973.

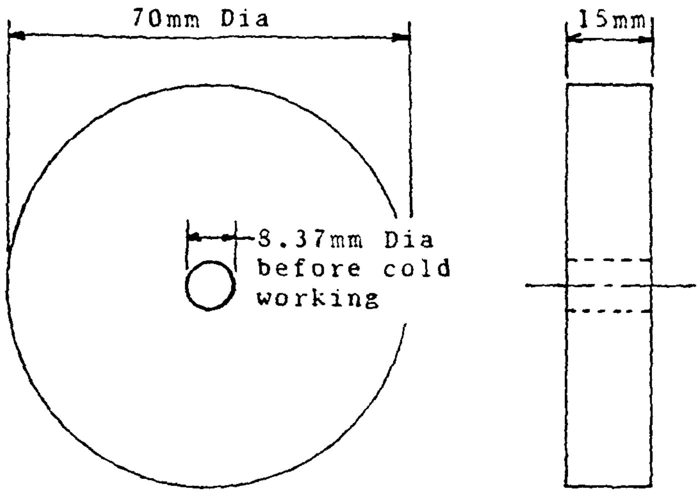


FIGURE 1: COLD-WORKED BOLT HOLE SPECIMEN

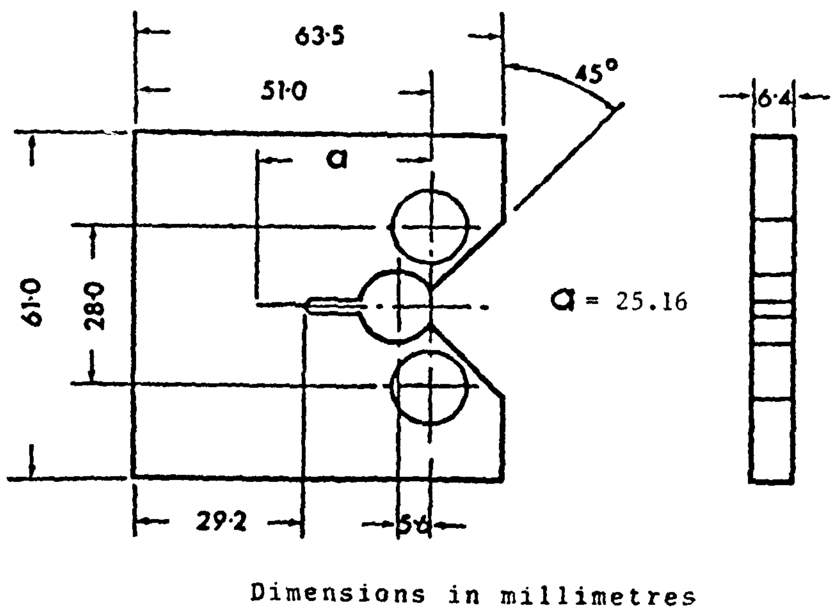


FIGURE 2: J-INTEGRAL SPECIMEN

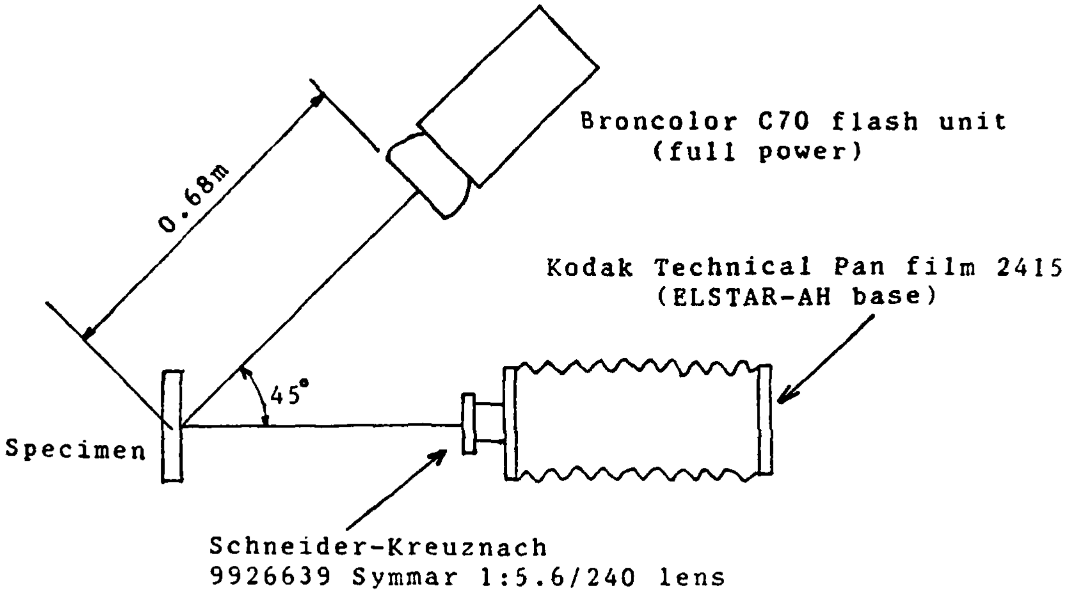


FIGURE 3: SCHEMATIC REPRESENTATION OF PHOTOGRAPHIC SET-UP FOR J-INTEGRAL SPECIMEN (VIEW FROM ABOVE).

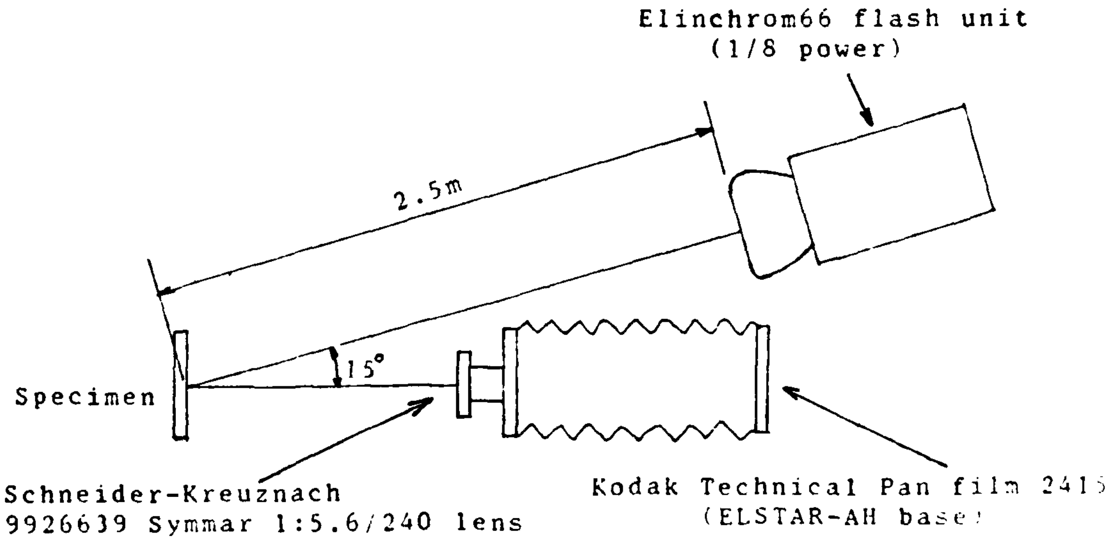


FIGURE 4: SCHEMATIC REPRESENTATION OF PHOTOGRAPHIC SET-UP FOR COLD-WORKED BOLT HOLE SPECIMEN (VIEW FROM ABOVE).

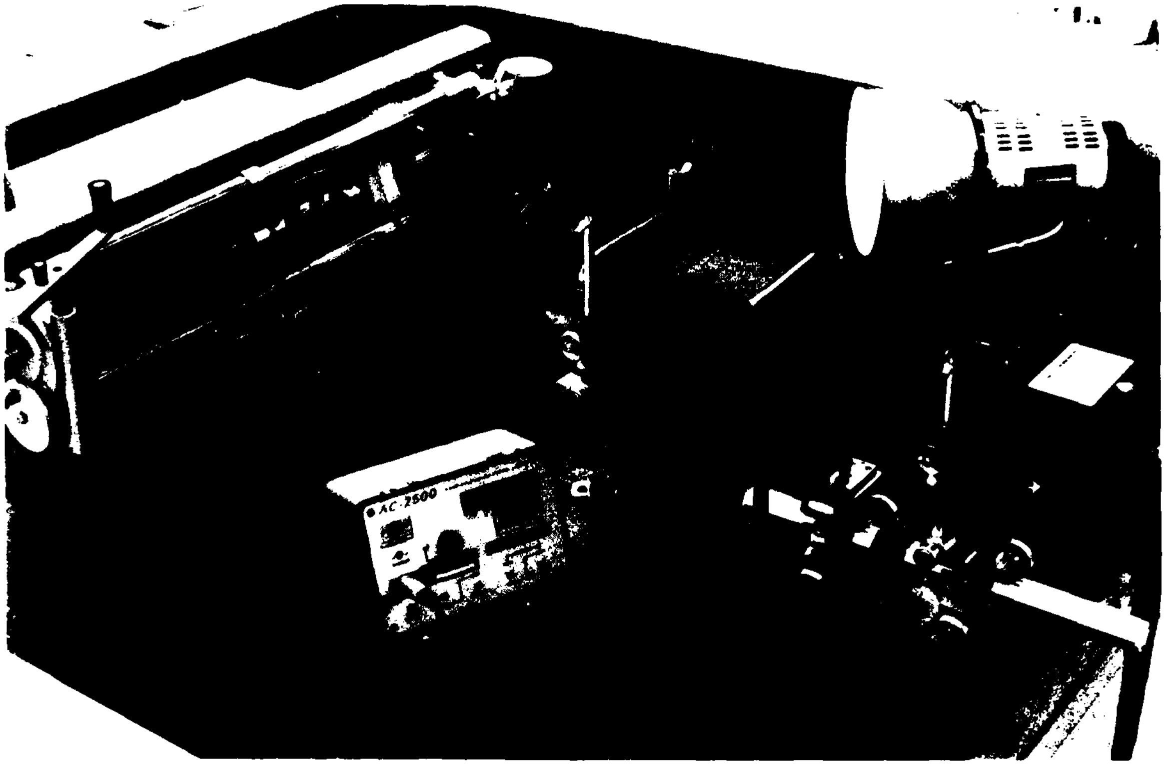


FIGURE 5: PHOTOGRAPHIC SET-UP FOR J-INTEGRAL SPECIMEN

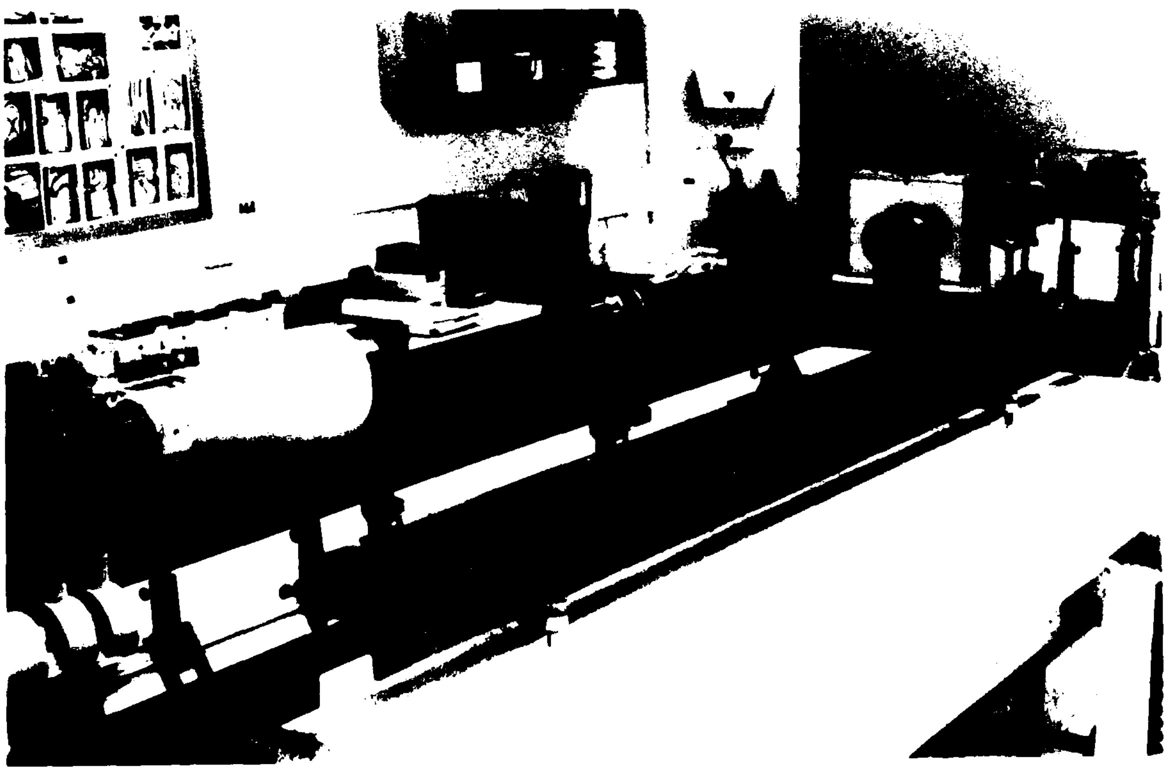


FIGURE 6: LAYOUT OF OPTICAL PROCESSOR

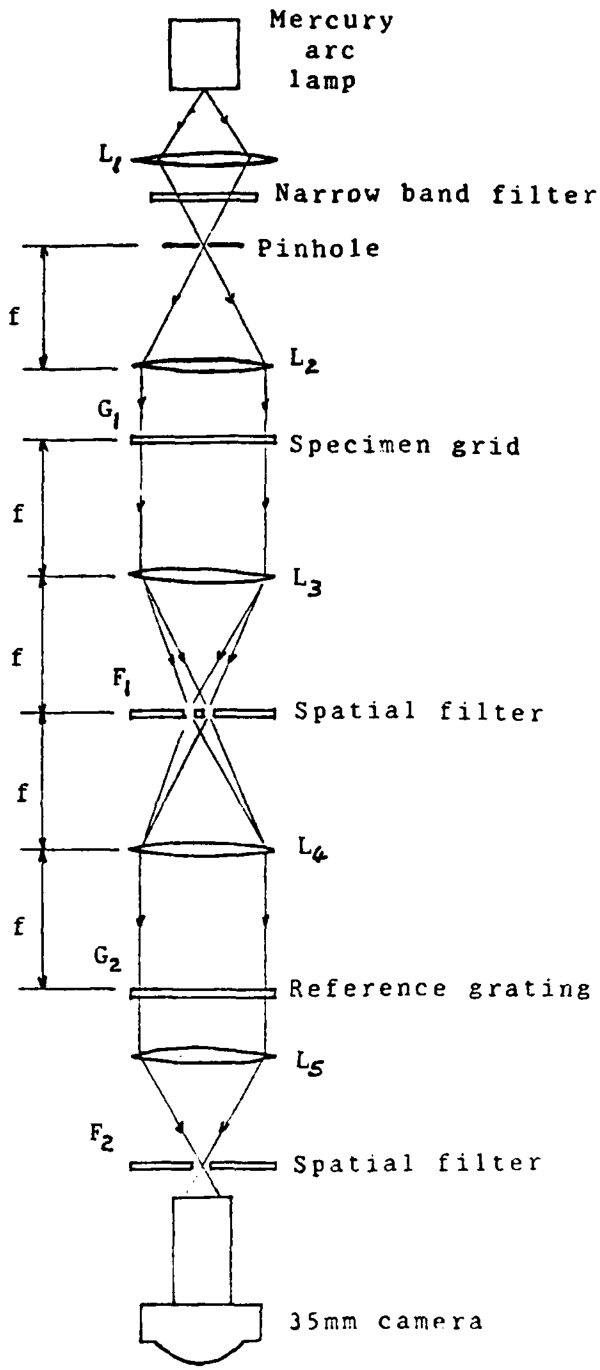


FIGURE 7: SCHEMATIC REPRESENTATION OF OPTICAL PROCESSOR

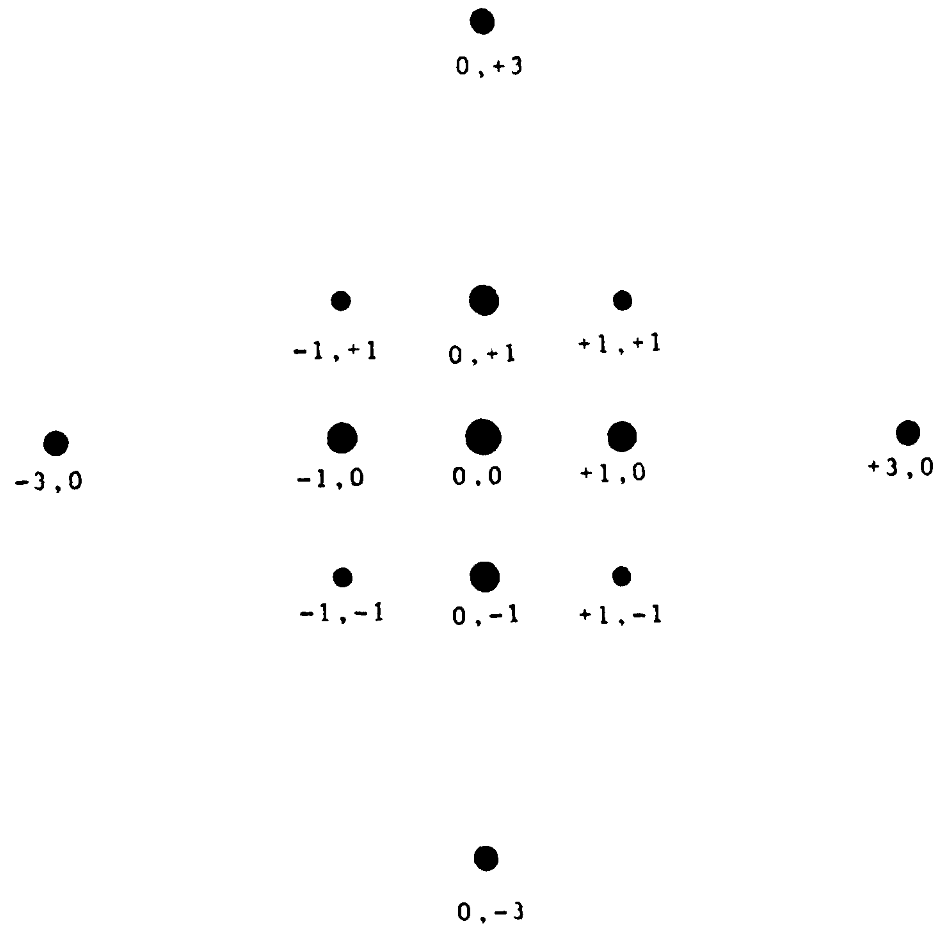
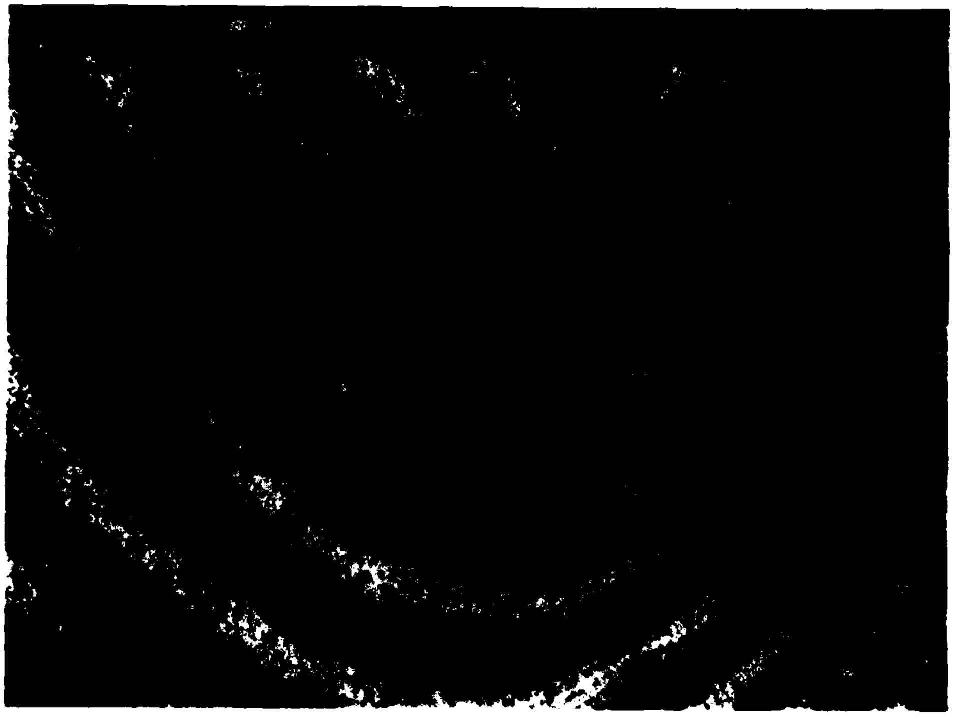


FIGURE 8: SCHEMATIC NEGATIVE OF FOURIER TRANSFORM OF SPECIMEN GRID.

(a) Horizontal Displacement



(b) Vertical Displacement

FIGURE 9: MOIRE FRINGE IMAGES FOR J-INTEGRAL SPECIMEN AT 3.17 kN

(a) Horizontal Displacement

(b) Vertical Displacement

FIGURE 10: MOIRE FRINGE IMAGES FOR COLD-WORKED BOLT HOLE SPECIMEN

DISTRIBUTION

AUSTRALIA

Department of Defence

Defence Central

Chief Defence Scientist
Deputy Chief Defence Scientist (shared copy)
Superintendent, Science and Program Administration (shared copy)
Controller, External Relations, Projects and
Analytical Studies (shared copy)
Counsellor, Defence Science London (Doc Data Sheet Only)
Counsellor, Defence Science Washington (Doc Data Sheet Only)
Defence Central Library
Document Exchange Centre, DISB (18 copies)
Joint Intelligence Organisation
Librarian H Block, Victoria Barracks, Melbourne
Director General - Army Development (NSO) (4 copies)

Aeronautical Research Laboratories

Director
Library
Divisional File - Structures
Authors: J. D'Cruz
B. Lawrie
K. C. Watters
S. J. Rumble
J. Sparrow
R. Jones
A. Wong
P. Beaver
J. Finney
T. Van Blaricum

Materials Research Laboratories

Director/Library

Defence Research Centre

Library

Air Force Office

Air Force Scientific Adviser
Technical Division Library

Department of Aviation

Flight Standards Division
Mr C. Torkington

C.S.I.R.O.

Division of Applied Physics
Dr B. Oreb
Dr P. Hariharan

Universities and Colleges

Monash
Hargrave Library

SPARES (10 copies)

TOTAL (57 copies)

Department of Defence

DOCUMENT CONTROL DATA

1.a. AR No	1.b. Establishment No	2. Document Date	3. Task No
AR-004-473	ARL-STRUC-TM-440	JUNE 1986	DST 83/006

4. Title	5. Security a. document	6. No Pages
EXPERIMENTAL ASPECTS OF IN-PLANE DISPLACEMENT MEASUREMENT USING A MOIRE FRINGE TECHNIQUE	UNCLASSIFIED	5
	b. title U, c. abstract U	7. No Refs 5

8. Author(s)	9. Downgrading Instructions
J. D'CRUZ, B. LAWRIE, K. WATTERS, S. RUMBLE	

10. Corporate Author and Address	11. Authority (as appropriate) a.Sponsor b.Security c.Downgrading d.Approval
Aeronautical Research Laboratories P.O. Box 4331, MELBOURNE, VIC. 3001	

12. Secondary Distribution (of this document)

Approved for public release.

Overseas enquirers outside stated limitations should be referred through ASDIS, Defence Information Services Branch, Department of Defence, Campbell Park, CANBERRA ACT 2601

13.a. This document may be ANNOUNCED in catalogues and awareness services available to ...

No limitations

13.b. Citation for other purposes (ie casual announcement) may be (~~select~~ unrestricted(~~or as for 13 a.~~

14. Descriptions	15. COSATI Group
Moire effects Displacements Optical processing	20060 14070

16. Abstract

A description is given of the techniques used to photograph gridded specimens and of the optical processing of the photographs to produce moire fringe images. Details and results of photographing the moire fringe images are presented.

This paper is to be used to record information which is required by the Establishment for its own use but which will not be added to the DISTIS data base unless specifically requested.

16. Abstract (cont.)		
17. Imprint Aeronautical Research Laboratories, Melbourne		
18. Document Series and Number Structures Technical Memorandum 440	19. Cost Code 276930	20. Type of Report and Period Covered
21. Computer Programs Used		
22. Establishment File Ref(s)		

END

12-86

DTIC